Strut and tie models for impact-loaded reinforced concrete beams

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Impact loads may arise due to collisions, falling masses, ballistics, or fragments. Flexural failure modes are generally desirable for reinforced concrete elements to safely absorb the incoming striker's kinetic energy. Flexural failures are characterized by wide cracks with significant plastic strain in the reinforcement, resulting in large energy absorption capacities. Shear-type failures are instead avoided, as these generally are characterized by one significant crack with minor plastic strain in the reinforcement, showing decreased energy absorption capabilities. Thus, models that can predict shear-type failures are needed, such that the beam can be reinforced against them. An agreed-on rational model for shear-type failures for beams without stirrups has yet to be found for static loading cases. However, reasonable models based on theories such as the Modified Compression Field Theory and the Critical Shear Crack Theory have been applied in design provisions. Since impact loads add to the complexity of shear-type failures, as inertia- and strain rate effects should also be considered, there is a need for an accepted model for shear and impact loads.

A simple strut and tie model was used to predict the impact capacity of impact-loaded beams tested in the lab. The beams were tested using a 70 kg mass dropped from 2.4 m. The response of the beams was monitored using load cells and a high-speed camera. Beams without and with stirrups were tested with different shear spans, both showing a significant influence on the shear capacity and failure mode. The strut and tie model considers the effect of the shear span and stirrup amount.

It was shown that a simple strut and tie model could predict both the transient response, characterized by an early peak in internal forces, and also the quasi-static shear capacity. The transient shear capacity generally converged with the model when longitudinal strains were not considered, indicating that significant cracks have not yet appeared through the compressive struts. The later quasi-static capacity was largely influenced by longitudinal strain in the strut. The model accurately incorporated the effect of both stirrups and shear span.